Top-Down Decarbonization

EES 3310/5310

Global Climate Change

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Considerations on Projections of Future Emissions

Grain of Salt

- Implied decarbonization rates depend on predictions of P, G, etc.
- Predicting population and economic growth are very tricky and imprecise.
- So take any of these calculations with a grain of salt.
- But are they still useful, despite the uncertainties?

Implied Decarbonization for Green New Deal

Kaya Identity

$$F = P \times g \times e \times f$$

- $F =$ emissions (million metric tons (MMT) CO_2 per year)
- $P =$ population (billions)
- $g =$ per-capita GDP ($1000 per person)
- $e =$ energy intensity of economy (quads / $ trillion)
  - Reducing e means increasing **energy efficiency**
- $f =$ carbon intensity of energy supply (MMT CO_2 / quad)
  - Reducing f means **replacing fossil fuels** with cleaner energy

US Green New Deal

US Green New Deal

- The Green New Deal has many definitions:
  - Resolution in Congress does not give specific emissions targets.
  - Bernie Sanders campaigned on a promise to completely eliminate CO_2 emissions by 2050 and reduce them 71% by 2030
    - $F(2019) = 4965$ MMT
    - $F(2030) = 1484$ MMT
    - Could we do this in 11 years?
      - We would have to cut *ef* by 13.4% per year.
      - Historically, since 1990, *ef* has dropped 2.5% per year.

How Can We Decarbonize?

Detailed Abatement Options

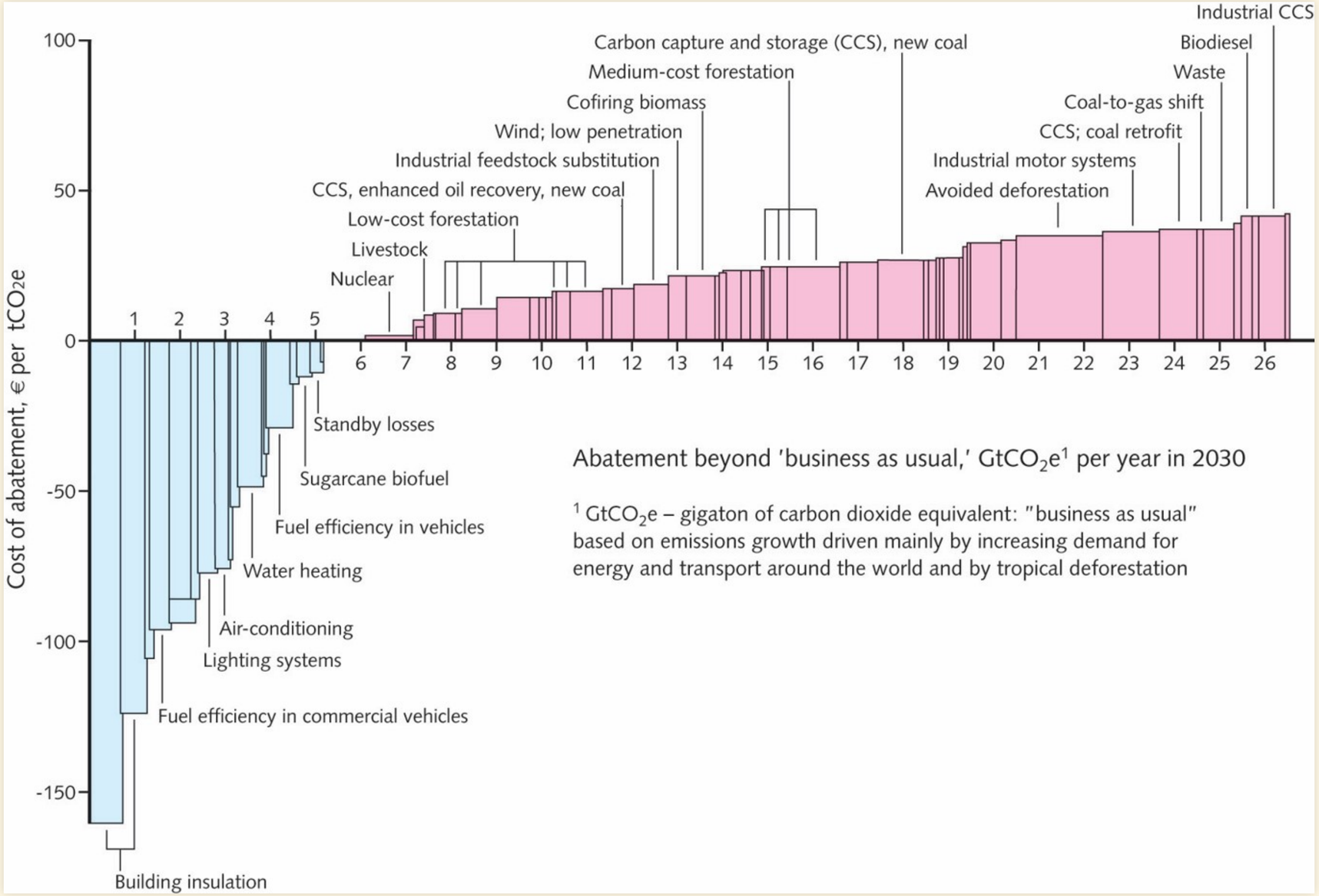
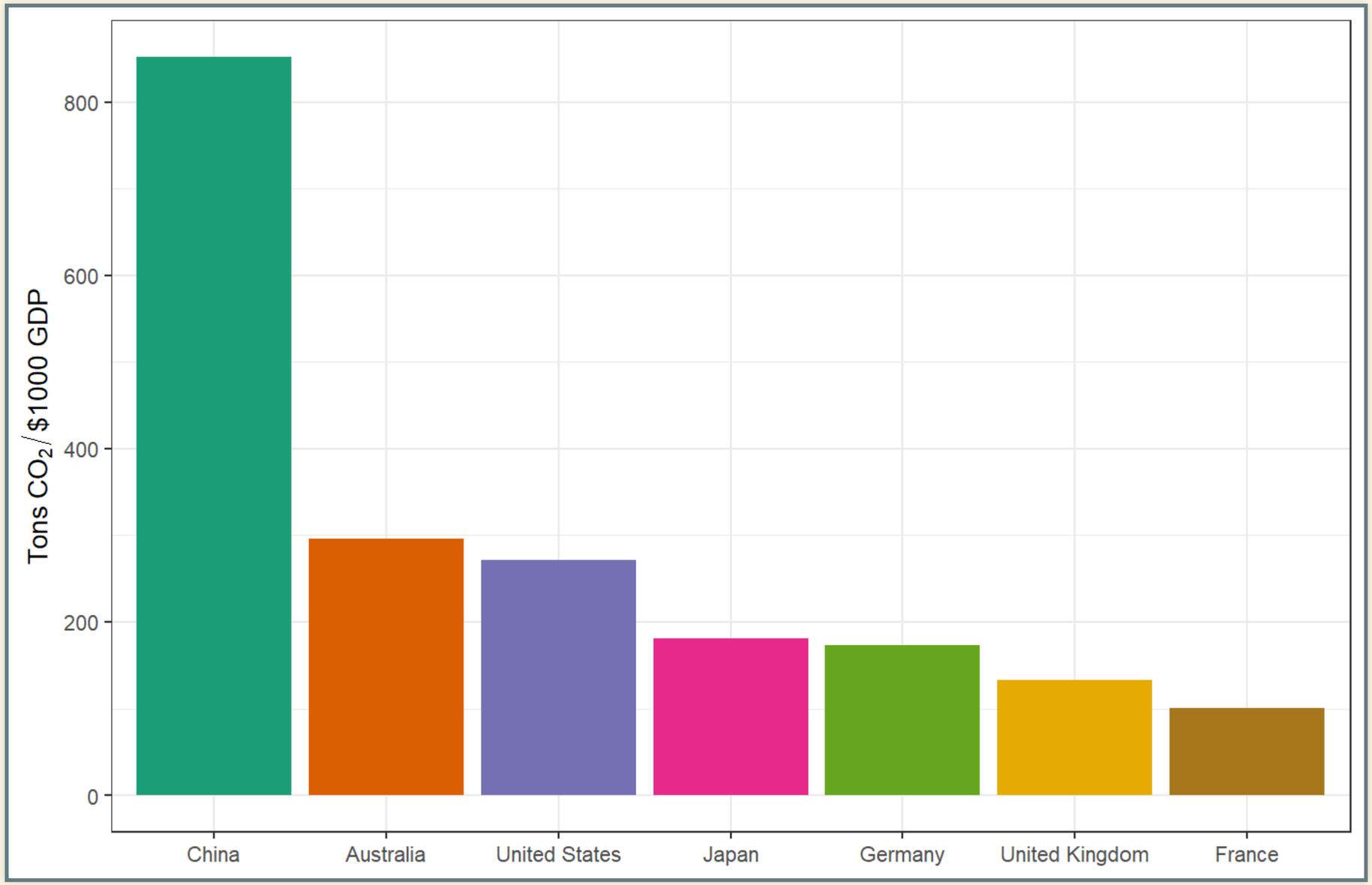
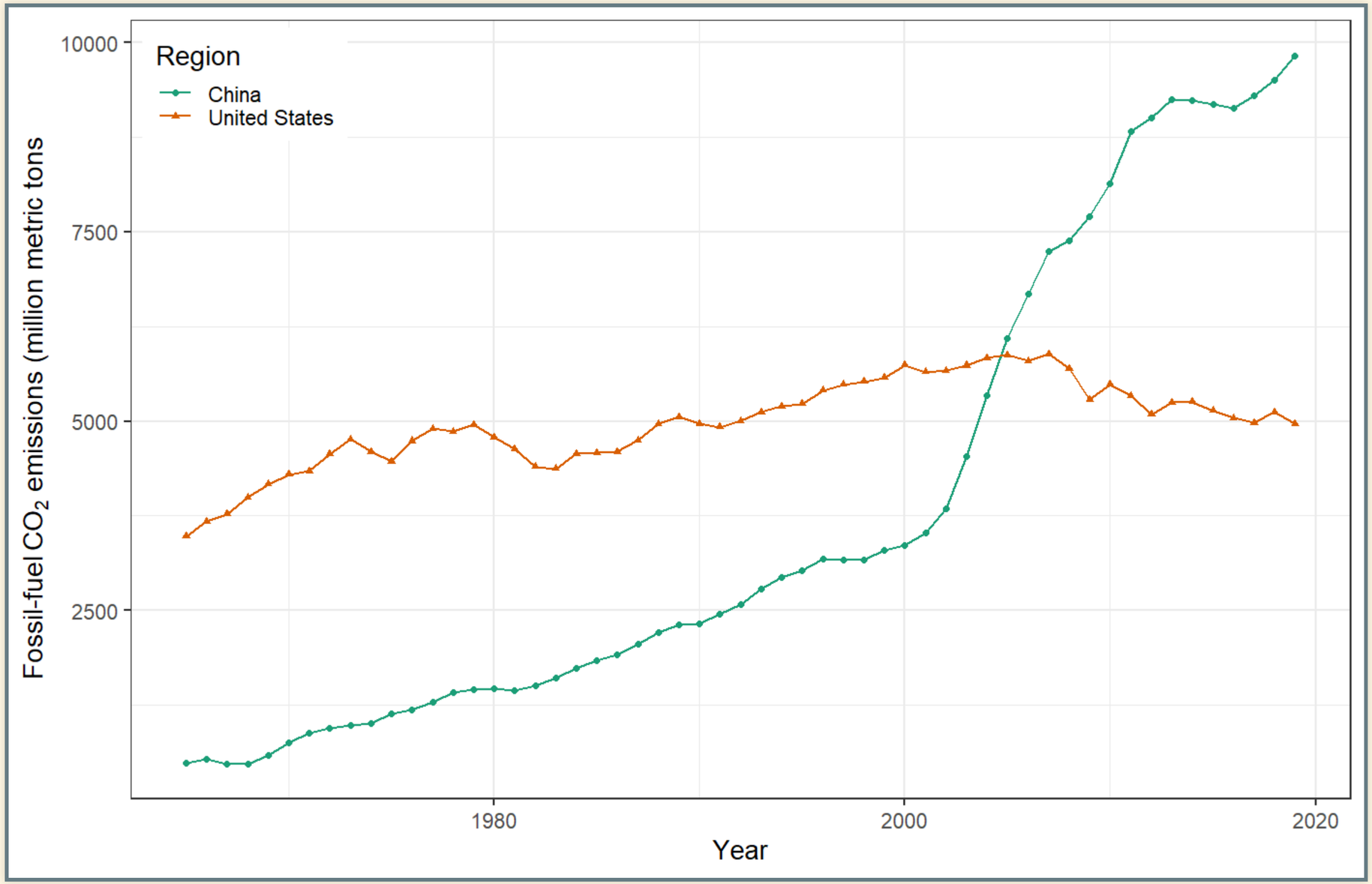


Image credit: McKinsey Global Institute

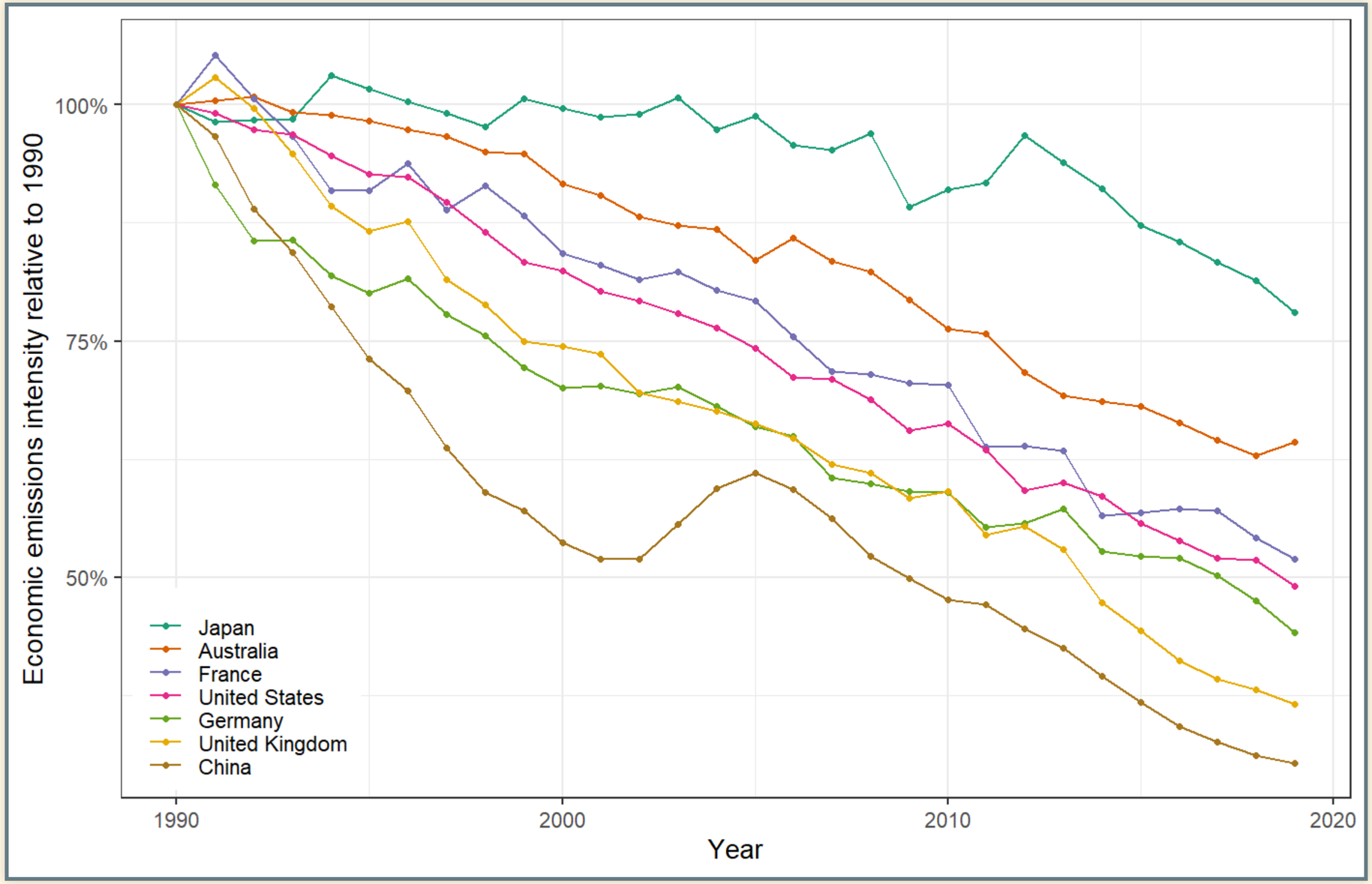
Economic Carbon Intensity in 2019



CO_2 Emissions 1965–2019



Relative improvement in carbon intensity 1990–2019

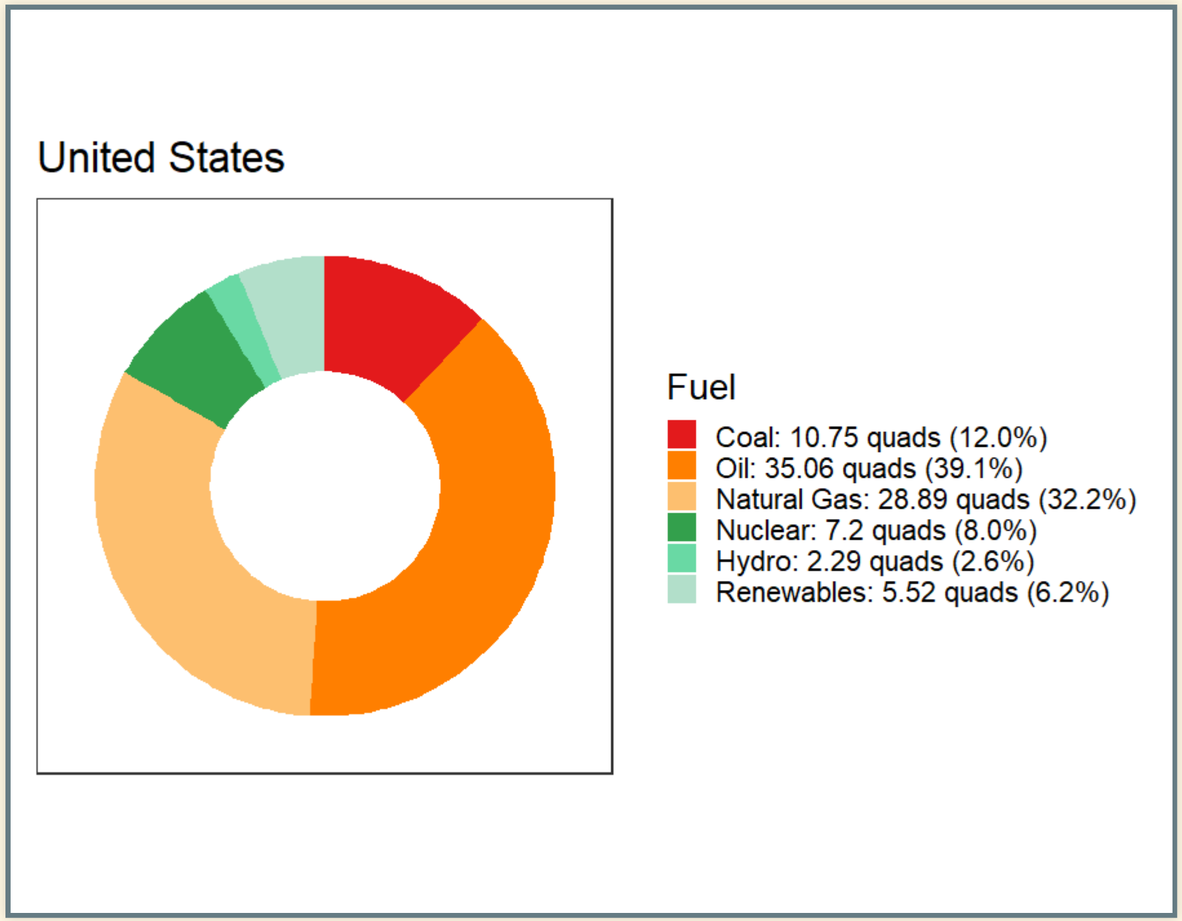


Top-Down Analysis for Green New Deal

Projected Energy Use in 2030

- Energy Information Administration top-down projection for energy demand in United States in 2030:
  - Total 2030 Primary Energy Use = 88.8 Quads
  - Assume P, g, and e are fixed.
  - Manage emissions by reducing f
    - Switch from fossil fuels to clean energy

Energy Mix in 2019



Fuel	Quads	%
Coal	10.7	12
Oil	35.1	39
Natural Gas	28.9	32
Nuclear	7.2	8
Hydro	2.3	3
Renewables	5.5	6
Total	89.7	100

Emissions Factors

Fuel	MMT CO_2 per Quad
Coal	94
Oil	70
Natural Gas	53
Nuclear	0
Hydro	0
Renewables	0

Projected Business as Usual Emissions in 2030

Fuel	%	Quads	MMT/Quad	MMT CO_2
Coal	12	10.6	94	1004
Oil	39	34.7	70	2428
Natural Gas	32	28.6	53	1518
Nuclear	8	7.1	0	0
Hydro	3	2.3	0	0
Renewables	6	5.5	0	0
Total	100	88.8	NA	4951

Top-down emissions-reduction

Fuel	%	Quads	MMT/Quad	MMT CO_2
Coal	12	10.6	94	1004
Oil	39	34.7	70	2428
Natural Gas	32	28.6	53	1518
Nuclear	8	7.1	0	0
Hydro	3	2.3	0	0
Renewables	6	5.5	0	0
Total	100	88.8	NA	4951

- Projected emissions for 2030 = 4951 MMT
  - If f doesn't change.
- Emissions goal for 2030 = 1484 MMT
- Must cut by (4951 − 1484) = 3467 MMT
- Start with coal:
  - Cut 1004 MMT (10.64 quads)
  - 2463 MMT left
- Next, cut gas:
  - Cut 1518 MMT (28.59 quads)
  - 945 MMT left
- Finally, cut oil:
  - Cut 945 MMT (13.49 quads)
- Total energy cuts = 10.64 + 28.59 + 13.49 = 52.72 quads.

Clean Energy Sources

- 11,000 megawatts (MW) for one year = 1 quad
  - (See Climate Fix, p. 97)
- **Nuclear Power Plant**:
  - 1000 MW × 75% capacity factor = **750 MW average**
  - 1 quad per year = 11,000 MW / (750 MW per nuclear plant) = **14.7 nuclear plants**
- **Solar Photovoltaic**:
  - 30 MW × 30% capacity factor = **9 MW average**
  - **1 quad = 1,200 photovoltaic solar farms**
- **Wind Turbine**:
  - 6 MW × 42% capacity factor = **3 MW average**
  - **1 quad = 4,400 wind turbines**

Meeting Green New Deal Goal

- Cut CO_2 by 3467 MMT
  - 1004 MMT from coal (10.6 quad)
  - 1518 MMT from gas (28.6 quad)
  - 945 MMT from oil (13.5 quad)
- Total clean energy needed: quads per year

- 53 quads × 15 nuclear plants/quad =
  770 nuclear power plants in 11 years
  (70 per year)
- 53 quads × 1,200 photovoltaic solar farms/quad =
  63,000 photovoltaic solar farms in 11 years
  (6,000 per year, or 100 per week)
- 53 quads × 4,400 wind plants/quad =
  232,000 wind turbines in 11 years
  (21,000 per year, or 60 per day)

Pielke’s Bottom Line

- Unfeasible to build so much clean energy so quickly
- Expense of building so much clean energy would defeat economic goals
- This is why we don’t have the technology to decarbonize as quickly as politicians and activists have been promising.

But ...

- Renewable energy is getting cheaper very quickly
- It may soon be profitable to shut down existing fossil-fuel power plants and replace them with renewables.

Review

Bottom-Up Analysis

- Start with individual Kaya-identity variables:
  - P, g, e, f
  - Figure out historical rates of change for each
- Gross Domestic Product: $G = P \times g$
  - Rate of change of G: $r_G = r_P + r_g$
  - Rate of change of a product is the sum of the rates of change of the factors.
  - Use rate of change of G to extrapolate G in the future

Bottom-Up Analysis

- Start with individual Kaya-identity variables
- Start with the policy goal: change in F.
  - Figure out implied rate of change of emissions r_F.
- Compare to the expected rate of change of GDP r_G.
- Calculate the implied rate of decarbonizing the economy, r_{ef}:

$$r_{ef} = r_F - r_G$$

- Compare implied r_{ef} to the historical trend in *ef* to assess the difficulty of meeting the policy goals.

Top-Down Analysis

- Start with macroeconomic estimate of future energy demand *E*
- Use mix of energy sources and emissions factors to calculate future emissions (*F*) if the mix of energy sources does not change.
- Your policy has a a goal for *F*
- Calculate difference between projected future *F* and policy goal for *F*.
- Calculate how many **quads of fossil-fuel energy** you would have to replace with clean energy to meet the policy goal.
  - Start with cutting coal, then cut natural gas, and finally cut oil
  - Why?
- Figure out how many power plants of different kinds you would have to build to supply the necessary clean energy.